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Phreatic surface flow from a near-reservoir saturated tongue

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Abstract

Steady and transient 2D Darcian flows in a saturated 'tongue' adjacent to a reservoir are studied analytically. First, a stable tongue receiving water from an inclined equipotential reservoir bed and losing moisture through a phreatic surface is considered. The hydraulic head is governed by the Laplace equation and the complex potential and complex coordinate are determined explicitly by the Polubarinova-Kochina method at an arbitrary bank slopes and evapotranspiration rates. In a particular case of a vertical slope, the tongue becomes a right-angled triangle extending into the layer for the same distance as the Dupuit-Forchheimer model predicts. Second, a saturated Dupuit-Forchheimer flow in the tongue is analyzed under the assumption of evaporation exponentially and linearly decreasing with the depth of a phreatic surface. The corresponding non-linear ordinary differential equation is integrated twice and predicts the length of the tongue as a function of the reservoir water level. Third, a transient regime is modelled by the Boussinesq equation with evaporation uniform in space, but varying cyclostationary with time. A straight-line water table translating upward–downward is found to be located always below the water table for steady regimes with an average evaporation.

Keywords: Groundwater; Phreatic surface; Hodograph; Analytic functions; Dupuit-Forchheimer model; Boussinesq equation

1. Introduction

Shallow groundwater flow and seepage in arid conditions is affected by capillarity and evapotranspiration losses of moisture into the vadose zone. The corresponding flux through the water table results in its dropping in unconfined aquifers and forming of perched or inverted water tables (free surfaces) encompassing finite-size saturated zones near surface water sources (reservoirs, channels, boreholes, and dripline emitters, among others, Polubarinova-Kochina, 1977; Stephens, 1996; Warrick, 1993).

Saturated–unsaturated flows are often modelled by a non-linear Richards equation. The equation for 2-, 3D flows is usually solved numerically with coefficients different in the two zones. In the near-reservoir saturated zone (Fig. 1a), the Laplace equation for a velocity potential appears as a limiting case of the Richards model while in the remote zone of a relatively dry soil the full non-linear equation should be considered. In this way, the free boundary problem is avoided and the zero-pressure interface AC can be reconstructed a posteriori from the numerical solution

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